THE COLORADO POTATO BEETLE IN CANADA.

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THE COLORADO POTATO BEETLE

(*Leptinotarsa decemlineata* Say)

IN CANADA

BY

Arthur Gibson, R. P. Gorham, H. F. Hudson, and J. A. Flock

INTRODUCTION

Among the insects which have been introduced into Canada in modern times, none have become so widespread, so well known to all the people, or have caused such great annual losses as the Colorado potato beetle. In the half century since its first appearance in Ontario it has become established in all of the provinces of the Dominion. The damage caused by the insect year after year and the annual expenditure necessary for its control together amount to an enormous tax on one of the great food crops of the country.

An intensive study of the insect was incepted by the senior author at Ottawa in 1919, and in that year and the following year he was assisted by Mr. J. A. Flock. Mr. H. F. Hudson undertook studies at Strathroy, Ont., in 1920 and 1921, and Mr. R. P. Gorham at Fredericton, N.B., in 1921 and 1922. In all of these investigations much new data have been assembled.

THE SPREAD OF THE COLORADO POTATO BEETLE IN CANADA

The natural home of the Colorado potato beetle (*Leptinotarsa decemlineata* Say) is supposed to have been along the eastern slope of the Rocky Mountains in the United States. Its northern limit in the wild state is not clearly known, and it may have reached that area of Canadian territory now known as the province of Alberta. As a potato insect it made its first appearance in Canada in southern Ontario in 1870, some years after it had become recognized as a pest in the mid-western United States. In *The Canadian Entomologist*, Vol. 2, p. 115, 1870, we find that Bethune recorded the appearance of the insect in the western part of the province of Ontario at Windsor, in the county of Essex, and at Colinville in the county of Lambton. This seems to be the earliest reference to the insect in Canada. Later in the same year, a further record[1] reported the presence of the beetle at Stratford, Ont., and Sarnia, Ont. Riley (1870)[2] records the finding of the insect near Point Edward, Ont., and near Windsor, Ont.

In June, 1871, the Commissioner of Agriculture and Public Works for the Province of Ontario authorized William Saunders and Edmund B. Reed to visit various parts of the province and investigate the extent of the potato beetle infestation. Their report[3] stated in part as follows:—

"We found that the districts most affected by the insect were those portions of the province situated on the frontier, between Sarnia and Amherstburg, and extending inland from twenty to forty miles; but we have obtained undoubted evidence of the fact that in smaller, but rapidly increasing numbers, this pest has spread over a very large portion of the province, embracing Bayfield to the north, the neighbourhood of Toronto to the east and over almost the entire western section of the country."

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[1] Canadian Entomologist, II, 134.
[2] American Entomologist and Botanist, II, 289.
[3] Canadian Entomologist, III, 41.

In the Report of the Entomological Society of Ontario for 1871 mention is made of the insect having reached Canada during the summer of 1870, but no further information is given on the extent of its spread.

Riley (1871)[4] described the method of crossing into Canada as follows:—

"In the spring the Detroit river was literally swarming with the beetles and they were crossing Lake Erie on ships, chips, staves, boards, or any other floating object which presented itself. They soon infested all the islands to the west of the lake and by June were common around London, and finally occupied the whole country between the St. Clair and Niagara rivers."

In July, 1871, larvæ were found at North Douro in Peterborough county, Ont., and in September of that year adult beetles were reported from as far east as Kingston, Ont.[5]

In 1873, Bethune reported that in its eastern progress it had traversed nearly the whole province of Ontario.[6]

In the "Autobiography of John Macoun, M.A."[7] the following statement appears: "Next day (July 27, 1872) we reached Fort Frances (Ont.) and for the first time saw the Colorado potato beetle and noted its power of destruction, as most of the potato plants were destroyed."

At the meeting of the Entomological Society of Ontario in 1874,[8] Bethune stated that the potato beetle "has now covered the whole of the province of Ontario and is very destructive throughout the western half of it.. .. .. In Quebec it is beginning to be observed."

The insect continued its eastward spread and in 1878 reached St. John, N.B.[9]

In 1879, Comstock reported that he had received specimens of the beetle from Manitoba[10] and, in 1880, Saunders[11] found the insect on Manitoulin island, Lake Huron, and was informed that it had been present there for several years previously.

A note published by Harrington[12] indicated that the beetle appeared in the province of Nova Scotia in 1881, and in 1883[13] the Legislature of Prince Edward Island passed an act for the suppression of the potato beetle wherever found on the island, so it is probable it had at that time made its appearance in the latter province.

In 1884[14], further reports were received from Manitoba which indicated a westward spread as far as Portage la Prairie. In 1887[15], Fletcher stated that the insect had "made itself apparent in Nova Scotia and Manitoba in such numbers as to demand the attention of farmers."

A report received by the Department of Agriculture in 1888 referred to a serious infestation in northern Ontario, near lake Temiskaming.[16]

In 1892, Fletcher[17] referred to the abundance of the insect on Prince Edward Island.

Of the further spread of the beetle westward there does not appear to be any record until 1899, when Gregson[18] recorded the presence of the insect "in

[4] Fourth Ann. Rep. Insects of Missouri, 1872.

[5] Canadian Entomologist, IV, 37, 200.

[6] Canadian Entomologist, V, 140.

[7] Published by the Ottawa Field-Naturalists' Club, 1922.

[8] Canadian Entomologist, VI, 184.

[9] Canadian Entomologist, X, 183.

[10] Canadian Entomologist, XI, 196.

[11] Rept. Ent. Soc. Ont., 1880, 8.

[12] Rept. Ent. Soc. Ont., 1882, 57.

[13] Laws of Prince Edward Island: An Act to Prevent the Spread of the Potato Bug, 1883.

[14] Canadian Entomologist, XVI, 207.

[15] Rep. Ent. & Bot., Dom. Exp. Farms, 1887.

[16] In a letter (July 30, 1923) received from Mr. W. C. Nixon, Agricultural representative, New Liskeard, Ont., the following appears: The Colorado potato beetle is present in the southern end of Temiskaming district in large numbers. It is also present in important numbers in the districts of Sudbury, Algoma and Thunder Bay.

[17] Rept. Ent. & Bot., Dom. Expt. Farms, 1892.

[18] Rept. Ent. Soc. Ont., 1899.

two or three places in Alberta ", and two years later it was reported from as far west as Pincher Creek and Calgary in the same province, and also from Moose Jaw, Sask.

Hewitt, in 1910[19], stated that the beetle was "gradually working its way north in Alberta, its northern limit at present being somewhere in the neighbourhood of Edmonton."

Recently, Dr. A. E. Cameron, of the University of Saskatchewan, informed us[20] that in the university collection are specimens of the beetle collected by the late Mr. T. N. Willing, at Walsh, Alberta, on August 23, 1901. There are, also, specimens from Cardston, Alberta, collected July, 1900. Dr. Cameron states, further: "I saw them in Regina in July, 1918, where they were pointed out to me by Mr. F. H. Auld, Deputy Minister of Agriculture, in his garden. According to Mr. Auld, they had been present in Regina for more than ten years, which would agree with the statement frequently made to me by the late Mr. Willing. In July, 1918, I observed it at Aylesbury, on the Canadian National Railway, which is about equi-distant between Saskatoon and Regina."

Mr. K. M. King, in charge of the Dominion Entomological Laboratory at Saskatoon, Sask., reported the species in 1923 from Estevan, Weyburn, Maple Creek, Ravenscrag, East End, Limerick, Palmer, Mossbank, Regina, Saskatoon, Rosthern, Speers and Prince Albert, all in Saskatchewan. In the same year we received at Ottawa a report that the beetle was present at North Battleford, Sask.

Professor E. H. Strickland, of the University of Alberta, reported the finding of the beetle at Edmonton, Alberta, on August 3, 1923.

So far as is known, the insect has never been able to cross the eastern range of the Rocky mountains by its own powers of travelling. Its introduction into British Columbia has doubtless been from the state of Montana. It was first found in British Columbia in 1919 at Gateway, B.C.,[21] and, in 1920, Mr. W. B. Anderson, Supervisor of Indian Orchards in British Columbia, reported an occurrence at Waldo, B.C. In 1921, Treherne,[21] and Eastham[22], recorded further spread within the province, namely, at Elko, Baynes Lake and Wardner Station. The latter has since made the statement[23] that the infestation in British Columbia is now practically continuous from the international boundary at Gateway, through Flagstone, Waldo, etc., along the Crow's Nest line of the Canadian Pacific Railway as far as Cranbrook.

THE HABITS AND BIONOMICS OF THE INSECT

Emergence from Hibernation in Spring

The natural emergence of the Colorado potato beetle from hibernation in spring occurs at or near the same date in any one locality year after year. An unnatural or forced emergence sometimes takes place at an earlier date, but this should not be confused with the natural emergence. When old potato fields are ploughed or harrowed in early spring in preparation for cropping, some hibernating beetles are brought to the surface, where, under the influence of bright sunlight, they become active and crawl around for a few hours, only to burrow into the soil again before sunset. This forced appearance sometimes gives rise to reports that the beetles are out at an earlier date than usual. In no case under our observations have any of these beetles thus forced out of the soil at an early date been seen to fly; and flight in search of food plants is one of the first acts of the beetles when they emerge naturally.

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[19] Rept. Ent. Soc. Ont., 1910.
[20] In litt.
[21] The Agric. Jour. Brit. Col. VI, 164.
[22] The Agric. Jour. Brit. Col., VI, 216.
[23] In litt.

The time of natural emergence varies in the different provinces of Canada, being later in the Maritime Provinces than in southern Ontario and Quebec. It appears to be directly regulated by soil temperature, so probably varies also from south to north in the interior provinces, although no information on this point is now available. The dates of emergence, in 1922, at different places in Canada, were as follows:—

Hemmingford, Que. (C. E. Petch), May 20.
Strathroy, Ont. (H. F. Hudson), May 23.
Ottawa, Ont. (R. C. Treherne), May 24.
Treesbank, Man. (Norman Criddle), May 26.
Fredericton, N.B. (A. B. Baird), May 30.
Grey's Mills, N.B. (R. P. Gorham), May 30.
Annapolis Royal, N.S. (A. Kelsall), June 5.

Slow heating of soil containing hibernating beetles in very early spring has shown that the beetles become active at 22° C. and burrow into the soil again when the temperature drops to 18° C. Soil temperature records taken at a depth of 6 inches in old potato fields have shown that temperatures of 22° to 23° C. prevail at the time when beetles first begin to emerge naturally.

From the soil of an old potato field, beetles may continue to emerge daily over a period of two weeks following the first general flight, and in a locality where there is considerable variation in soils and in exposure of slopes to sunlight emergence may be continued over a longer period. Large numbers of beetles are found hibernating at depths of six to eight inches and lesser numbers at greater depths. When the surface soil becomes warm from the sun's rays in spring, those beetles nearest the surface become active some days earlier than those at a greater depth. In the wintering cages used in New Brunswick in 1921 and 1922 emergence began on May 30, the same date that beetles were first seen in the field, and continued for nineteen days, the last individual coming to the surface on June 18. Examination of one cage on June 16 revealed three healthy beetles in a state of hibernation, at a depth of fifteen inches. The cages in this instance were on a clay soil where a potato crop had been grown the previous summer.

Flight in Search of Food Plants

When they emerge from the soil in spring, the beetles are hungry and take flight in search of food almost at once. They appear able to direct themselves toward the nearest field of young potato plants and the loss by straggling, if there is any, is probably small. One field of young plants near an old potato field from which the beetles are emerging may act as a trap crop and protect another field at a greater distance for a time. An interesting instance of this was noted in 1922 on a farm isolated from other farms by bodies of water and forest. Two fields of young plants were under observation; one 200 yards from an old potato field known to contain a large number of beetles, the other a quarter of a mile distant. The beetles began to emerge on May 30 and the potato field close by was at once attacked by large numbers of the insect. Not a single beetle was found in the field a quarter of a mile distant until June 7, and the plants of that field had the advantage of a full week of growth without beetle injury.

Large potato plants appear more attractive to the beetles than small ones at the time of their first flight in spring, and during the first few days of egg-laying, more egg masses are deposited on the large plants than on the smaller ones. An instance of this was noted in New Brunswick in 1921 when collections of egg masses were made on two plots of potato plants equally distant from an old potato field from which beetles emerged. One plot was a week ahead of the other in date of planting and markedly so in growth. It numbered

504 plants and during the first week of beetle activity yielded 873 beetles. The other plot of 724 plants yielded 725 beetles in the same time. When egg-laying began, the early plot yielded on June 4, 6 and 8, 241, 425 and 285 egg masses, respectively, as compared with 40, 50 and 45 egg masses on the same dates from the plot of smaller plants. At harvesting, July 28, the early plot had yielded 1,964 beetles, or 3·8 per plant, while the later plot had yielded 2,139 beetles, or 2·95 per plant.

Mating

Food appears to be necessary before mating in spring but copulation may take place very soon after the insects have had a chance to eat. Males and females dug up from hibernation in spring have been kept together for two weeks without food and have shown no desire for mating, but three hours after potato foliage had been given them to eat they were found mating freely. Beetles have been found in copula in the afternoon of the day they emerged from the soil and fertile egg masses have been found two days later. If the day following emergence is fine and bright, mating is usually common in the fields, but a rainy or cold day delays it for a time. The search of the males for mates is noticeable in the field, the insects flying slowly about over the plants from row to row. The females in flight are more direct, going from one plant to another. When they alight, they travel to the highest point of the plant, where the males find them. The males are aggressive in mating and usually effect union quickly. This may continue over a considerable period—from sixteen seconds to several minutes or an hour—and may be repeated with the same or another female within a quarter of an hour.

Tower[24] mentions that copulation may continue "up to ten or twelve hours" but no instance of union lasting more than one hour has come under our observation. The average of many unions timed in the insectary was found to be a few seconds short of five minutes and of thirty-seven timed in the field, a little over eight minutes.

Copulation is very frequent all through the egg-laying period and appears to be promiscuous to a marked degree, the female accepting any aggressive male. Marked individuals have shown this in the insectary, as may be seen from the following table:—

				Time
Male A + female A	united 10.37^{40}	a.m.	separated 10.45^{16}	—7 min. 36 sec.
Male B + female B	united 11.00	a.m.	separated 11.04^{30}	—4 min. 30 sec.
Male B + female A	united 11.07^{40}	a.m.	separated 11.13^{10}	—5 min. 30 sec.

Thus female A united with two different males with an interval between of twenty-one minutes.

Male B united with two different females with an interval between of only three minutes and ten seconds.

Tower[24] states that as a result of this promiscuous mating, the receptaculum seminis of the female may contain the spermatozoa of several different males and hence, the offspring of one female, may have several different males for the other parent.

In insectary tests a three-day period has usually been found between copulation in spring and the laying of the first egg mass. Eggs are sometimes found in the field on the day following emergence from the soil, but it is possible that such eggs may have been laid by beetles fertilized the previous autumn. Several tests made at Ottawa, Ont., Strathroy, Ont., and in New Brunswick have shown that among beetles dug up from hibernation in early spring and confined in individual cages, there are some which can lay fertile eggs without mating that season. Other insectary experiments at Ottawa and

[24] An investigation of Evolution in Chrysomelid Beetles of the genus Leptinotarsa: Carnegie Institution. Washington, D.C., 1906.

Strathroy have shown that female beetles may hibernate through two winters and lay fertile eggs in the summers of two years. Therefore, to account for egg masses found in the spring very soon after emergence, we have three classes of females:—

1. Beetles which have hibernated over two winters and are still able to lay fertile eggs.
2. Beetles which have copulated and laid eggs the previous year and have retained their fertility over winter.
3. Beetles of a summer brood which have copulated in the fall before going into hibernation, but have not laid eggs.

At Ottawa, it was found that beetles of the first summer brood would mate within four days after emergence from the pupal stage. Under New Brunswick conditions, where there is but a single generation in the year, mating could not be brought about in the insectary between beetles of the summer brood. Males of the 1921 brood were found to mate readily with females of the 1920 brood but not with females of the 1921 brood. Mating was observed in the field in late fall, which, however, appeared to be between members of the summer brood.

Polygamy and polyandry appears to be the general rule, and at Ottawa it was found that one female might copulate almost daily through active life from sexual maturity to death. It was also found that males confined together would try to copulate with one another. These results agree exactly with the observations made in New Brunswick.

That copulation is not necessary for the fertilization of each egg mass is shown by the fact that females in cages have continued to lay fertile eggs for two weeks after the death of the male. Also, that females dug up from hibernation in spring have continued to lay fertile eggs over a period of one month while in solitary confinement. At Ottawa, it was found that the males of the summer brood went into hibernation early in autumn and that females continued to lay fertile eggs for two weeks afterwards.

Oviposition

Position of Egg Masses.—Egg masses are sometimes found in unusual places, such as on sticks, grasses, weeds, etc., and occasionally, when the potato plants are just pushing up through the soil, on the earth itself. Compared with the number laid on the plants, these are of little importance and some of the larvæ from them die before reaching the food plants. The eggs of most importance are those laid on the leaves of the potato plant. Records of the positions of 3,455 masses in 1921 and 1,485 masses in 1922, showed that by far the greater proportion of all egg masses were laid on the underside of the three terminal leaflets of the compound potato leaf. In 1921, 85 per cent of the egg masses collected were found on these leaflets and in 1922, 92 per cent (Fig. 1).

In early spring the greatest number of egg masses are laid on the largest leaves, which, at that season, are the leaves nearest the ground. In July, when the plants have attained large size, the egg masses are found in the dense parts of the foliage mass, about midway between the bottom and the top of the plants.

The eggs are attached to the leaf surface by a quick-drying liquid forced out with them from the ovipositor of the female. When placed on the leaf they are at first directly on end, but by the mechanical action of the female in moving after depositing each egg, the tip of the egg is pressed backward until it rests at an angle to the leaf. The placing of a number of rows of eggs against one another and all sloping at the same angle leaves a small part of the side of each exposed, a possible provision for ease of hatching.

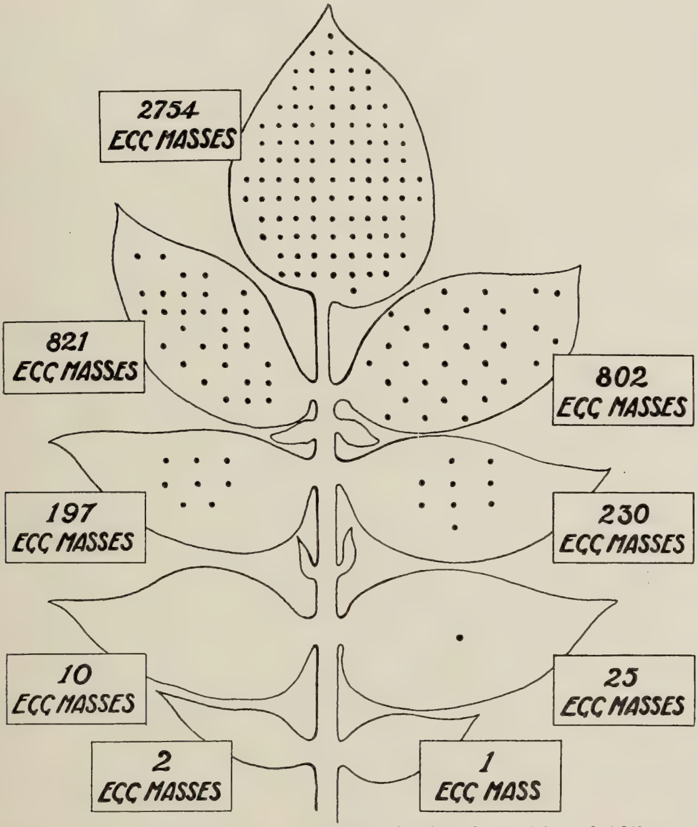


Fig. 1.—The compound leaf of the potato showing the position of 4,842 egg masses collected in the years 1921 and 1922. Each dot represents 25 egg masses. 88 per cent of the egg masses are laid on the three terminal leaflets. (Original)

Numbers of Eggs per Mass.—An egg mass contains on an average about thirty eggs, although much larger and smaller masses are common. The number of eggs per mass varies in different fields. A collection of seventy-five masses from one field will give a certain average number while similar collections from other fields on the same day will show quite different averages.

During June and the first part of July, collections of eggs were made from different fields in New Brunswick and the eggs per mass counted. The average per mass was found to vary somewhat in different fields on the same day. The table below gives the results. The different lots on the same date indicate that they were from different fields.

THE AVERAGE NUMBER OF EGGS PER MASS, GREY'S MILLS, NEW BRUNSWICK, 1921

Date	Number masses counted	Total number eggs	Average per mass
June 2	75	2,272	30·2
" 2	75	2,328	31·0
" 2	35	940	26·0
" 2	28	516	18·4
" 2	53	1,577	29·7
" 7	75	2,529	33·5
" 7	75	2,606	34·7
" 8	75	2,414	32·1
" 10	71	2,197	31·2
" 22	75	2,744	36·5
" 29	75	2,625	35·1
July 4	75	3,050	39·1
" 4	34	1,134	33·3
	821	26,932	$\frac{410\cdot8}{13}=31\cdot6$

At Ottawa, Ont., 100 egg masses were collected on June 9, 1919. Altogether, these masses contained 2,880 eggs. The greatest number of eggs in a single mass was 58 and the smallest number 6. The average number per mass was 28.8.

In the same year a further collection of 100 egg masses made between July 9 and August 8 was studied. The total number of eggs in these masses was 2,438. The greatest number in a single mass was 129, the smallest number 6. The average number per mass was 24.38.

The largest number recorded in our experiments in a single mass was 144, laid under insectary conditions, the beetles having been kept in darkness for a long period of time.

The total number of eggs laid by individual beetles in captivity varies widely, and averages varying from 200 to 800 have been found by different investigators. At Strathroy, Ont., one record was obtained of 1,042 eggs laid by a single female, which seems to be the maximum for Canada, although numbers much greater than this have been obtained in the United States by Tower[24], Girault[25] and Ellis[26].

The female beetle can lay about two eggs per minute, and if undisturbed, will lay the whole mass of thirty or more at the same rate. If disturbed, egg-laying may be much slower and the eggs may be scattered instead of being placed in a compact mass.

The female may continue to lay at intervals over a long period, which may include two summers. Daily laying, however, is rarely continuous for more than nine days. After depositing the first egg mass in spring, the female usually rests for one or more days before depositing another egg mass. After the laying of the second egg mass, there is frequently another rest and then follows a period when an egg mass is deposited daily for from five to nine days. A number of breeding records show these daily egg-laying periods and it is perhaps worthy of note that there is usually one egg mass laid during such a period which contains considerably more than the average number of eggs. Following this period of daily egg-laying, there is usually a rest for a number of days during which the female may lay a few masses at irregular intervals. Then follows another period of daily egg-laying lasting from six to nine days, as before, and then another rest period. Egg-laying may continue for some time

[24] An investigation of Evolution in Chrysomelid Beetl.s of the genus Leptinotarsa: Carnegie Institution, Washington, D.C., 1906.

[25] Further Notes on the Colorado Potato Beetle; Annals Ent. Soc. Amer., I. 155.

[26] Jour. Econ. Ent., VIII, 520.

following this and occasionally there is a third period of daily egg-laying later. The two periods in June and the first part of July are usually well marked in all records of individual egg-laying, and the third less distinct or wanting.

Each period of daily egg-laying may be described as a " peak " period of egg production for the individual beetle and when the " peak " periods of many individuals coincide, as egg records of many experiments show that they do, they constitute a " peak " period of egg abundance in the field. When the eggs hatch, there are well marked waves of larval abundance recognized by the potato grower.

A series of egg-laying records obtained at Ottawa, Ont., in 1919, show that there were " peak " periods between June 13 and 18 and between July 1 and 9 in the case of overwintering beetles; and between July 26 and 31 with the beetles of the summer generation. Egg records obtained at Strathroy, Ont., in 1920, show that there were " peak " periods of egg production between June 12 and June 16, and between July 3 and 15. These show considerable uniformity and indicate that it may be possible to find particular dates for a given locality when sprays may be most advantageously applied to destroy the larvæ hatching from eggs laid during such annual " peak " periods.

One overwintering female beetle may continue to lay eggs over a period extending from emergence at the end of May to the middle of August in one year, and continue for an unknown time the following year. A female of the summer generation may lay from the third week of July to the second week of September, as shown by records kept in experiments at Ottawa, and continue for an unknown period the next year.

In one instance at Ottawa, a beetle deposited eggs on thirty-seven days throughout the season although the average of a number of others was only 14.4 days. So far as is known, the egg-laying record of one beetle has not been kept for more than one summer by any investigator.

Eggs are commonly deposited most freely during the hours of bright sunlight and not at all at night. Field observations where all egg masses were removed, at sunset, from plots of one hundred plants and the plants examined again in the early morning have failed to show that any eggs are laid at night. Experiments conducted at Ottawa in which the beetles were kept in a dark, underground insectory for varying periods during the egg-laying season, have also failed to show that eggs are ever deposited during the hours of darkness. Some experiments conducted in insectary cages have indicated that the partial shading of such cages from direct sunlight may reduce the number of eggs deposited.

THE EGGS

The eggs are elongate-oval in form, about one-fourteenth of an inch in length and without markings. Usually they are lemon-yellow in colour when deposited, but are sometimes of a darker shade. As incubation proceeds, they become reddish-yellow and about twelve hours before hatching show plainly the eye spots and hatching spines of the embryo within.

The length of the egg stage varies widely under different climatic conditions. At Ottawa, the egg stage was found to vary from five to ten days during June, with a mean temperature of 71° F. In a test with the eggs kept in total darkness in an underground insectary at Ottawa at a constant temperature of 60° F. and humidity of 100°, they were found to hatch in from eleven to fourteen days. Twelve egg masses (274 eggs) were used in this experiment, the average number hatching per mass being 14.6. In New Brunswick, from fourteen to seventeen days have been required for hatching in June with a mean temperature of 58° F. the cold winds and rains having a retarding effect on incubation. The warm weather of mid-July shortened the period to from seven to ten days.

From studies of the egg instar made by Girault[27] sufficient data were recorded "to show that during the period covered, the instar is about inversely proportional to the variation in temperature; that is to say, when the instar is long, the daily average effective temperature is low, and conversely," and in Ohio is, on an average, 5.4 days with a minimum of four days and a maximum of nine days. Girault and Zetek [28] have drawn attention to the fact that "there exists variation in the duration of embryonic development for batches of eggs deposited at the same time, hence subject to the same environmental factors, including temperatures," eggs laid by different beetles within forty-five minutes of one another varying as much as fourteen and a half hours in time of hatching under similar conditions of temperature and humidity.

At Ottawa, in 1919, 24.5 per cent of the eggs collected in the field on June 9 were found to be infertile. A number of the egg masses had been attacked by a fungous growth. One hundred egg masses, containing 2,880 eggs, were under observation.

Immediately following, further careful search was made in the fields for infertile eggs and also for eggs attacked by the fungus. Numbers of eggs were found which had dried up, but only a small number of eggs which had been attacked by the fungus were found. In the province of New Brunswick the percentage of non-hatch has not been found to exceed one per cent in either of the two years that investigational work has been carried on.

Exposure to direct sunlight appears to have no injurious effect on the eggs, as shown by tests of 500 masses at Grey's Mills, N.B., in 1922. The leaves of the plants were turned over and fastened so that the direct rays of light would strike the eggs, but hatching went on naturally. Other eggs masses deposited on the wires of cages out-of-doors also hatched in a normal manner.

Hatching.—During embryonic development, three hatching spines are formed on each side of the thorax by "pyramidal thickenings of the hypodermis" (Wheeler)[29]. By bending the body within the egg shell, the fully developed embyro forces the centre spine of one set of three through the wall of the shell. By further movements this spine is forced to cut a short distance upward and downward in a longitudinal direction. This cutting is carried just far enough for the other two spines to catch in the opening and continue the cutting farther, one cutting upward and the other downward. The net result is a slit in the egg shell extending for a little more than one-half its length on one side. It is worthy of note that while the embryo larva has hatching spines on both sides of the thorax, the egg shell is cut only on one side, the side left exposed by the placing of the eggs at an angle against one another in the egg mass.

After the slit has been cut in the wall of the egg shell, parts of the thoracic and first abdominal segments are pushed out by the bending of the larval body with the two ends pressed against the opposite wall. When pushed out far enough, the hatching spines on both sides catch on the edges of the cut egg shell and serve as a fulcrum on which the body, acting as a lever, turns, drawing the head and thoracic legs clear of the shell. The legs then help to some extent in pulling the body clear of the shell and are aided by the small backwardly pointing setæ on the abdomen, which spring erect as soon as free and serve to prevent any backward movement as the larva wriggles. When the greater part of the body is free, the larva remains resting for a time while the free parts are moved about and exercised. During this period, which commonly lasts about three-quarters of an hour, the larva hangs head downward, held in position by the tip of the abdomen, which is pressed firmly against the inner wall of the egg shell. During this resting period the legs, head capsule, and last body segments, darken in colour and the whole larva changes in appearance, becoming

[27] Annals Ent. Soc. Amer., I, 155.
[28] Annals Ent. Soc. Amer. IV, 71.
[29] Journal of Morphology, III, 366.

more robust and sturdy than when it first appeared. At the end of the resting period the tarsal claws catch on other eggs near and the abdomen is drawn free from the shell. The larva then begins to feed on the eggs, or egg shells, within reach. The body wall is still semi-transparent and the digestive organs can be seen in motion as the first food passes in. Eighteen hours after hatching the body wall is much darker and the movements of digestion are no longer visible.

The following notes on the hatching of an egg mass were taken in New Brunswick on August 3, 1921:—

9.10 a.m. Two larvæ with heads free, a third just bending body out through cut egg shell.

9.13 a.m. Head and thorax free. Tips of mandibles reddish-brown, tips of palpi black; eye spots reddish-brown; last tarsal segments black.

9.17 a.m. All legs free. The small backward pointing setæ on the body seem to assist in getting the larva out of the egg shell. By convulsive movements, the body is pulled out a short distance and one or more of the setæ freed which at once spring erect, preventing backward movement.

9.30 a.m. Larva standing erect with five segments of abdomen free from the egg shell, supported by tip of abdomen fixed to inner wall of shell. Moving legs backward and forward constantly. Head capsule beginning to darken in colour.

9.44 a.m. Larva bent over and clawing at other egg shells in endeavour to get foothold. Legs darkening rapidly in colour.

10.00 a.m. Head, thoracic shield and legs getting quite dark in colour.

10.15 a.m. Abdominal segments beginning to show dark colour.

10.15 a.m. Larva free from the shell; last three abdominal segments darker than the others.

11.00 a.m. Three more larvæ beginning to emerge.

3.00 p.m. Seventeen larvæ out, two eggs not hatched. Larvæ eating egg shells.

THE LARVÆ

Feeding Habits.—The larvæ on emergence from the eggs, measure, on an average, 2.4 mm. in length with a head capsule .7 mm. in width. The normal first food of the larvæ consists of the egg shells from which they have emerged, but no discrimination is made between empty shells and unhatched eggs. On cool days, when hatching goes on slowly, the first larvæ out often feed upon the helpless ones within the shells, or those part way out. In one instance observed, an egg mass of twenty-seven eggs had, at the close of the hatching period, only eleven larvæ, the others having been destroyed either while in or partly out of the egg shells, by the larvæ which hatched first.

After eating most of the egg shells, the larvæ from an egg mass commonly begin to feed on the leaf tissue near the egg mass, cutting out small bits of the tissue of the underside of the leaf but not breaking the upper epidermis. After this first leaf feeding, the larvæ migrate to the top of the plant, usually on a bright, sunny morning. As they go, they separate to different branches so that the larvæ from one egg mass will be scattered and the whole top of the plant will become infested. On the top of the plant the larvæ feed upon the upper surface of the young tender leaves and are conspicuous as small, black and red "slugs."

After feeding for two days on the upper surface of the leaves, the larvæ moult, usually retiring to the underside of a leaf for the purpose. Not all the larvæ from one egg mass moult at the same time or on the same day. Field observations of clusters of larvæ known to have hatched from one egg mass rarely show more than one or two larvæ moulting at once. Girault and Zetek[28] found that in Illinois moulting of the larvæ from one egg mass sometimes extended over a period as long as twenty-three hours. At Ottawa, an average

[28] Annals Ent. Soc. Amer., IV, 75.

period of three days was found between hatching and the first moult and three days between each of the following two moults. In New Brunswick, under spring conditions, a period of five days usually elapses between hatching and first moult and three days between each of the following moults.

The larvæ at all stages are very hardy and can stand cold rains lasting several days. They seek shelter on the undersides of the leaves and, although they become somewhat torpid when the temperature drops to 50° F., they are not easily dislodged.

After the first moult, the larvæ feed upon older foliage to some extent but still remain near the top of the plant. They prefer the most succulent portions of the plant and at first leave the mid-ribs and larger veins untouched. After the second moult they will feed upon these portions also and when the foliage of the plant is consumed, they will feed upon the main stems. Feeding goes on freely during the night, as may be seen by examining certain branches on which larvæ are feeding at night and in the morning. At Ottawa, tests were made of feeding in total darkness in an underground insectary and these have shown that the larvæ develop as rapidly in the dark as in the light. The same result was obtained in New Brunswick with specimens reared from eggs in closed boxes.

The most feeding occurs after the third moult, and when a number of larvæ in the field reach this stage, rapid defoliation of the plants follows. Feeding continues up to within a few hours of the time the larva prepares to pupate. Slight differences in the colour of individuals can be seen at this time but rearing tests have indicated that these have no relationship to the sex of adults.

Careful measurements by planimeter and balance at Ottawa have shown the amount of food consumed by a definite number of larvæ between hatching and pupation.

On July 5, 1919, at Ottawa, newly-hatched larvæ were put in shell vials with a definite known area of leaf tissue. Each larva was placed on a measured leaf at a known hour and left for a definite length of time. Then the leaf was removed and the area eaten by the larva measured. New leaves were put in the vials and measured each time, the experiment extending from the day the larvæ hatched until they entered the soil for pupation. The following table is a record of the area of leaf tissue eaten by ten larvæ during their various instars:—

AREA OF LEAF TISSUE EATEN BY TEN LARVÆ OF THE COLORADO POTATO BEETLE DURING THE LARVAL PERIOD. LARVÆ HATCHED AND EXPERIMENT BEGUN JULY 5, 1919

Larval number	Length of 1st instar, in days	Area eaten during 1st instar, in square inches	Length of 2nd instar in days	Area eaten during 2nd instar, in square inches	Length of 3rd instar, in days	Area eaten during 3rd instar, in square inches	Length of 4th instar, in days	Area eaten during 4th instar, in square inches	Total area eaten by each larva from hatching to pupation
1	3	0·14	3	0·46	4	0·89	5	1·72	3·21
2	3	0·13	3	0·29	3	0·58	5	1·94	2·94
3	4	0·20	2	0·16	3	0·55	7	3·88	4·79
4	4	0·20	3	0·69	3	0·51	6	3·04	4·44
5	3	0·11	2	0·21	3	0·55	6	3·51	4·38
6	4	0·15	2	0·28	5	0·90	6	3·10	4·43
7	4	0·19	2	0·31	4	0·75	6	2·80	4·05
8	4	0·18	2	0·22	4	0·85	7	4·10	5·35
9	3	0·16	3	0·32	4	0·79	7	3·99	5·26
10	5	0·20	3	0·40	3	0·69	6	2·95	4·24
Total.....	....	1·66	....	3·34	....	7·06	....	31·03	43·09
Average..	3·70	0·166	2·50	0·334	3·60	0·706	6·10	3·103	4·309

The 10 larvæ devoured in 15 days, the average length of the larval period, 43·09 square inches of leaf tissue.
Twenty-five potato leaves taken from the plants and weighed in a moist chamber = 9·9280 grams.
Area of 25 leaves 53·48 square inches.

Therefore $\dfrac{9\cdot9280 \times 43\cdot09}{53\cdot48} = 7\cdot99$ = amount in grams eaten by 10 larvæ.

On this basis one hundred larvæ would devour 79.9 grams, or .175 pounds of leaf material (1 pound = 453.59 grams) during their various instars.

Number of Larvæ per acre.—Estimates prepared at Ottawa, based on the eggs laid by overwintering and first generation beetles in the insectary, indicated that the larval population of an acre would be, under ordinary conditions, 140,000 by June 13; by the third week of June it would be as great as 320,000, after which the number would decrease slightly but would continue around 250,000 per acre during July.

Movements from Plant to Plant.—While there is foliage for food there is no movement of larvæ away from the plant on which they were hatched. When, through overcrowding, food becomes scarce, the larvæ will travel to adjoining plants in search of a better supply. In this movement the larvæ act independently, scattering in different directions and seemingly in an aimless manner, some reaching the adjoining plants in the same row of potatoes and others going a considerable distance to plants in other rows.

When forcibly dislodged from their food plant by wind, rain, or the passing of cultivating implements, the larvæ start creeping along the ground in the same aimless way. In the potato field they are almost sure to reach a food plant but when feeding on wild plants, it would seem that there must be some loss by straggling away from food.

PUPATION

When the feeding period is completed, the larvæ leave the plant and scatter to some extent in search of places for pupation. This movement from the plants usually occurs during the sunny part of the day, most larvæ being seen burrowing into the soil between 10 a.m. and 3 p.m. When the soil is loose and open, a large proportion of the larvæ will burrow in at once beneath the plant on which they fed. When, however, the ground is hard and crusted from the effects of rains and sun, the larvæ will often travel considerable distances to find a suitable place to enter. Advantage is taken of any holes or crevices which offer a good chance for burrowing. In a clay field, where the soil had dried and cracked following rains, almost all larvæ were found entering the cracks and in places they formed almost continuous lines along certain cracks, which, in this instance, were between the potato rows.

The depth at which pupation occurs varies widely with soil conditions. Some larvæ that find crevices or earthworm holes will penetrate to considerable depths, while others in hard soil go just below the surface. In the field, pupæ have been found at depths of from one-half inch to six inches below the surface.

In order to find at what depths pupation would occur in firm compact sand, free from cracks or holes, a large box was filled with fine river sand, well shaken down, and then moistened from below by capillary rise of moisture. One hundred larvæ were put on this sand and supplied with fresh leaves until all had entered the soil or pupated. One week after the last larva had pupated the sand was removed, one inch at a time, and the pupæ counted. The results were as follows:—

On surface..	2	pupæ
1st inch..	10	"
2nd "	24	"
3rd "	39	"
4th "	9	"
5th "	0	"
6th "	1	pupa
Dead larvæ at different depths..	15	
	100	

A similar experiment was conducted at Ottawa. On June 24, 1919, 100 mature larvæ were allowed to pupate in a 12-inch flower pot filled with soil. On July 3, the soil was disturbed and the pupal cells examined. Pupæ were found at depths of from two to eight inches. Seventy-five per cent were found at a depth of six inches.

In the field at Ottawa, on June 27, 1919, pupæ were found at a depth of from one to three inches and in August of the same year at an average depth of five inches.

A curious feature noted in digging up larvæ in the prepupal period is that the small, weak setæ commonly present on the last stage larva are missing, probably broken off in digging into the soil.

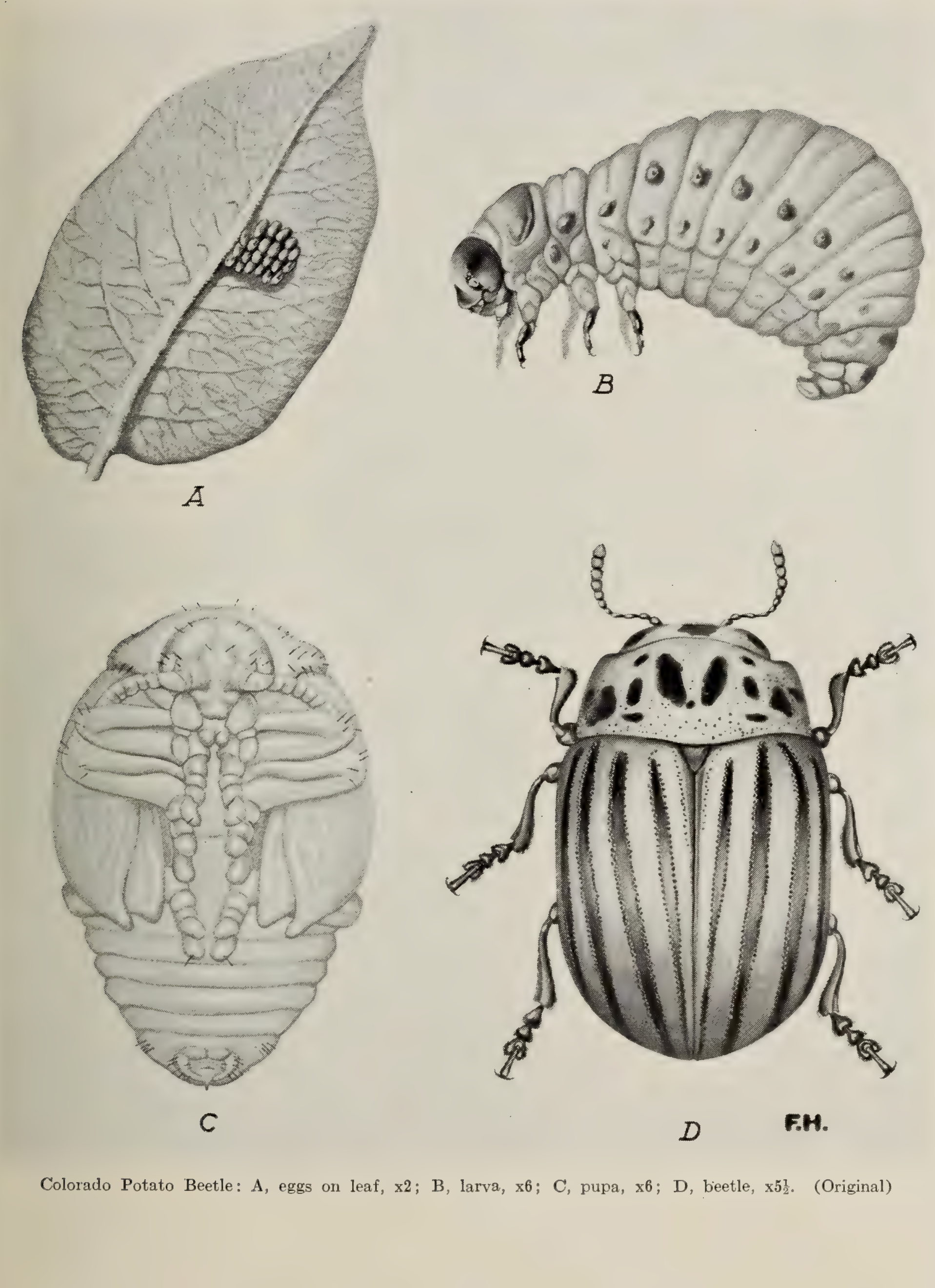
Pupal Cells.—In a moist clay loam soil the larva was observed to press out, by moving and turning around, a small oval cell in which to transform. This act was observed several times in glass tubes of soil where the glass formed one side of the cell. As far as could be seen, no secretion of any kind was used to cement the walls, and evidence in support of this was noted in loose loam and sand soils where no cells were formed. Even in clay loam the cell walls were found to be so fragile that none of them could be taken out intact.

The presence or absence of the pupal cell would seem to have little effect on development. One jar of sand loam soil containing ten larvæ was emptied out on a dish daily during the prepupal and pupal periods, shaken around so that all larvæ or pupæ could be seen, and then poured back into the jar. The ten larvæ developed into beetles of normal size and activity in the same time that undisturbed larvæ did. Larvæ kept in cardboard boxes and in vials without any soil also transformed to beetles in the usual time and seemingly without any injury.

The Prepupal Stage.—After entering the soil the larva remains quiet for from three to five days, the body shortening and thickening during this period. The prepupal period is closed by the shedding of the last larval skin. At Ottawa this period was found to be three days in length; in New Brunswick it was found to be five days.

This operation is an interesting one to watch and differs from any of the previous moults and from the shedding of the pupal skin to follow, in that the old skin is cleared from the abdomen first and later from the thorax and legs. The skin splits along the dorsum and is worked clear of the abdominal segments by strenuous wriggling. A broad and strong caudal spine is revealed terminating the end of the body. By bending the body ventrally, this is brought forward, and, catching in the old skin, helps to pull it free from the legs and head.

The Pupal Stage.—When first out of the last larval skin, the pupa is light-orange in colour, but in a short time loses much of its brightness and becomes yellowish-white. All the body and its appendages, wing covers, legs, antennae and palpi, are covered with a very thin, transparent covering, the pupal skin. A feature of this skin is that it bears an armature of setæ, larger and more numerous than is found on the larva at any of its stages, and which do not appear at all on the adult beetle. Over the thoracic shield there are scattered strong setæ; there are three small setæ at the base of each wing cover, two on the scutellum, a row across the posterior margin of the metathorax, scattered ones on the margins of all the abdominal segments, clusters of them near each of the spiracles and seven wart-like protuberances on the sides of the abdomen which bear large setæ. Clusters of small setæ also occur on each leg. In addition, there is the large caudal spine mentioned earlier in this account.



Colorado Potato Beetle: A, eggs on leaf, x2; B, larva, x6; C, pupa, x6; D, beetle, x5½. (Original)

The length of the pupal stage is variable, being doubtless subject to the influence of temperature and moisture. In the District of Columbia, U.S., Johnson and Ballinger[30] found the maximum period to be ten days and the minimum six days. Girault and Zetek[28] record a range of from ten to fifteen days in Illinois. Ottawa experiments have shown thirteen to fifteen days to be the range in that locality. In New Brunswick, in 1921, the period varied from seven to eleven days. One larva kept in a watch glass on the stage of a binocular microscope was observed to shed the last larval skin on July 22 and the pupal skin on July 27, a period of only five days.

THE BEETLE

Getting clear of the pupal skin required twenty-two minutes in the case of one insect observed and twelve minutes more were needed to clear the skin from the underwings. When just out of the pupal skin, the beetle is very soft and uniformly light orange in colour. Between three and four hours pass before the first faint red lines, indicating the position of developing wing stripes, are visible. The stripes gradually darken in colour and eight hours after shedding the pupal skin the beetle is normal in appearance. It is probable that under field conditions this period is passed in the soil, for the beetles without stripes are not seen on the plants. Under insectary conditions, however, where the beetle was reared free from soil it was found that it would begin feeding on potato leaves before the wing stripes developed. The wing covers remain soft for a number of days, and in late autumn, for two weeks.

The newly emerged beetles feed freely, but the experiments at Ottawa go to show that they do not consume a larger amount of food at this time than at any other period.

The beetles are most active on warm, bright days, and egg-laying goes on freely under such conditions. During cold nights in early spring the beetles seek shelter in the soil near the base of the plant or under bits of turf or small stones nearby. After a night of frost that was severe enough to kill potato leaves, many beetles were found under small stones, which had possibly retained more heat than the surface soil.

The beetles appear to require a considerable amount of moisture and in the insectary cages will go eagerly to the drops of water to drink when the food material is sprinkled. There is a possibility that some of the early deaths and early hibernation records obtained in cages indoors may be due to lack of moisture.

The beetles fly freely on warm days and find practically all the potato plants in an ordinary settled district. One instance was noted when an obstacle appeared to have an effect on flight. A small potato plot in 1921 was separated from another field, which had been planted in 1920, by a long set of barns and other buildings. One end of the 1921 plot projected beyond the buildings and it was noted that large numbers of beetles collected on that end of the plot and laid numbers of eggs, but did not spread to the other part of the field until a week later. The farm, in this case, was isolated by water and forest from other potato fields. It simply illustrates that obstacles may have some influence on flight and that a range of hills may prove quite a barrier in some instances. Three notes of potato beetles flying considerable distances have been obtained from officers of the Entomological Branch.

Mr. M. B. Dunn reported that at a camp on the headwaters of the Salmon river in New Brunswick, twelve miles in the woods from the nearest settlement, he planted a few hills of potatoes in 1919 and that before midsummer they were found to be heavily infested with potato beetle larvæ.

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[30] Jour. Agric. Research, V, 922.

[28] Annals, Ent. Soc. Amer., IV, 77.

Messrs. R. S. Hawkins and R. H. Mowat reported that while engaged in 1921 on spruce budworm survey work in New Brunswick, they were encamped one day at the foot of the falls on the Upsalquitch river, 22 miles in the forest from any settlement, and were surprised to find two potato beetles on the side of their tent. This was only two miles from an abandoned lumber company farm at the upper end of the rapids, but so far as they could learn, no crop of any kind, other than grass, had been grown there for four years.

Somewhat similar to this was a report from Messrs. A. H. MacAndrews and J. D. B. MacFarlane, engaged on the same survey in another part of New Brunswick. They reported that when encamped on Burnt Hill Brook, 30 miles by river and approximately 18 miles in a direct line from Boiestown, the nearest settlement, a potato beetle flew down and alighted near the food they were preparing for dinner.

Feeding Habits.—At Ottawa, it was found that when beetles emerged before potato plants were up, they fed freely upon several weeds—pigweed, thistle, lamb's quarters, and a species of grass. They also fed upon tomato plants and egg plants in a hotbed. A report was received from the Fredericton Experimental Station in 1921 of the beetle feeding freely upon young bean plants.

Feeding upon tomato plants is a common occurrence in mid-June, even when potato plants are abundant. Eggs are rarely laid on the tomato, however. In late September, 1921, potato beetles were found feeding voraciously on tomato plants and on green tomatoes in the field after all potatoes were harvested. Feeding on potatoes left on the field at harvesting is a common habit in late fall.

An extensive investigation was carried on at Ottawa, in 1919, to find what quantity of food material was consumed in a given time by beetles of different ages. The following table gives the results of this investigation. Each vial contained one beetle.

THE AREA EATEN BY ADULT BEETLES UNDER VARYING CONDITIONS OF TEMPERATURE AND HUMIDITY

Vial Number	Area eaten by newly emerged adults in sq. ins. Max. temp. 86° Min. temp. 58°	Area eaten by beetles 24 hours old, in darkness for 24 hours Temp. 60° Humid. 120°	Area eaten by adults in darkness for 24 hours Max. temp. 85° Min. temp. 55°	Area eaten by males in 48 hours Max. temp. 85° Min. temp. 55°	Area eaten by females in 48 hours Max. temp. 85° Min. temp. 55°
1	1·19	0·22	1·13	0·67	0·55
2	1·03	0·91	0·82	0·80	1·23
3	0·96	0·66	1·32	1·18	1·70
4	1·93	1·21	1·13	0·52	1·49
5	1·53	0·48	1·18	0·64	2·60
6	1·57	0·24	0·95	0·49	2·16
7	0·92	0·38	1·22	0·55	0·51
8	1·39	1·30	1·75	0·76	0·71
9	1·68	1·08	0·79	0·59	1·92
10	1·60	1·30	1·56	0·83	1·57
Total	13·80	7·78	11·85	7·03	14·44
Total in 48 hours	....	15·56	23·70	....	....
Average	1·38	1·55	2·37	0·70	1·44

From these results it was concluded that:—

1. Newly-emerged beetles do not devour any more leaf tissue in a given time than fully developed adults five or six weeks old;
2. Female beetles devour more than twice the amount of food on an average than do males;
3. The beetles feed more during the night than during the day. A prolonged period of darkness causes a marked increase in feeding.

Numbers of Beetles per Acre.—At Ottawa, in 1919, counts were made, every two weeks, of the beetles found on ten blocks of ten plants each in different parts of the field. These counts indicated an acre population of about 15,000 beetles daily during the month of June and first week of July. Between that time and July 20 the population dropped to about 3,000 per acre, possibly through poisoning of the adults in sprayed fields or by beetles going into hibernation at an early date. After July 20, the adults of the summer generation began to appear in very large numbers and at the end of August it was estimated that there were more than 1,000,000 beetles per acre. Interesting data on the number of beetles of this summer generation coming out of the soil in a small space were obtained by placing a cage over two defoliated plants in a block of unsprayed potatoes and counting the number of beetles which emerged from the soil beneath the cage. The cage was 1½ feet wide, 2½ feet long and 1½ feet high. Between August 1 and August 27, the last day beetles emerged, 250 beetles were collected beneath the cage, or sixty-six to the square foot of soil surface. The beetles came out in such numbers between August 2 and August 12 that it was estimated that under acre conditions and similar infestation, there would be over 100,000 adults emerging daily.

In fields of late potatoes when the adults of the summer generation had emerged, square rod plots were measured off from time to time and the beetles collected and counted. The following brief table shows the numbers found:—

COLLECTIONS OF POTATO BEETLES ON SQUARE ROD PLOTS, N.B., 1921

Date	Place	Males	Females	Total	Number per acre
Aug. 15	Gorham Farm	208	149	357	57,120
" 16	Sterrett Farm	193	140	333	53,920
" 20	Neville Farm	191	131	322	51,520
" 30	Neville Farm	228	129	357	57,120

In 1922, collections of beetles were made daily on three plots of plants on different farms at Grey's Mills, N.B. One plot of fifty plants yielded 1,113 beetles between May 3 and July 27 =322,770 per acre. One plot of fifty plants yielded 1,442 beetles between June 1 and July 30 =418,180 per acre. The third plot of seventy-five plants isolated from old potato fields, yielded 1,330 beetles between June 7 (when insects first found it) and July 31 =257,468 per acre. The average of the three plots was 332,806 per acre. These estimates are all based on 14,520 plants per acre.

The daily collections in the field showed that there was a constant movement of beetles from place to place, the plots yielding nearly the same number each fine day after the middle of June. There is the possibility that the very slight injury to the foliage of plants from which the beetles were removed daily may have made those plants more attractive to the beetles than others in the field on which larval feeding occurred.

Sex Ratio at Different Seasons.—The males and females are so nearly alike that it is only by an examination of the genital organs that sex of potato beetles can be definitely determined. By separating the genital plates with the point of a needle while observing through a low power microscope, the sexes can be quickly and accurately determined.

Sex determinations of 3,741 beetles collected at different times in 1921 showed that when the beetles first emerged from the soil in spring there were more females than males, the proportions being 1.54 females to one male. One week later, the proportions changed to 1.33 females to one male, indicating that males had been a little slower in coming out of the soil than the females. The general average of all collections between May 30 and July 25 was 1.29 females to one male. Almost the same proportions were found in 1922.

Sex determinations of 1,051 beetles of the summer generation in 1921 and 700 in 1922, collected on late potatoes in August, show that at that season the males outnumber the females to some extent, the proportion being 1.32 males to one female. These notes would seem to indicate that there may be a greater death rate among males during the winter than among females. In this connection it is interesting to note that in late summer there are usually a number of imperfectly developed beetles in the field, beetles with one wing cover undeveloped, with one wing cover blackened or with a wing protruding sideways, and also beetles of less than normal size. These are not seen in spring so it is apparent that such crippled or weak individuals die during the winter.

Length of Life.—A number of experiments were carried on to find the length of life of individual beetles. These experiments began with the overwintering beetles on emergence in spring and all have shown that in insectary cages there are some deaths each week throughout the summer. The one important feature which these experiments have shown is that a number of beetles live through the summer and go into hibernation for a second winter. At Ottawa, out of one hundred overwintering beetles collected in spring, thirty-seven survived the summer and again went into hibernation during the latter part of August. Of these, thirty individuals emerged the following spring and some of them deposited eggs but unfortunately their life-history that year was not followed.

In New Brunswick experiments, only seventeen beetles out of one hundred survived the summer and hibernated for the second winter. None of these emerged the following spring, but it must be noted that in other wintering cages containing some 4,000 beetles the death rate was very high that winter. The experiments indicate that we do not know the length of life of the beetle and that to find it definitely it will be necessary to start with adults reared from the larvæ instead of with overwintering individuals of uncertain age.

FOOD CONSUMED IN A SEASON

The average length of the larval stages were found to be fourteen days for both generations at Ottawa. From notes on the time when beetles emerged in spring and when they went into hibernation it was estimated that the overwintering beetles had an active feeding period of thirty-five days. For beetles of the summer generation the active feeding period was found to be twenty-five days. A general average of thirty days was thus found for both generations and formed the basis for calculating that each beetle consumed 18.54 square inches of leaf during the season. 53.48 square inches were found to weigh 9.92 grams, so 18.54 square inches equalled 3.42 grams =.00759 pounds.

In the following table is shown the total food consumed in all stages, amounting to 228.54 square inches for ten individuals in one season, equal to 42.38 grams, or 4.23 grams for each insect.

THE TOTAL AREA OF LEAF TISSUE DEVOURED BY 10 SPECIMENS OF THE POTATO BEETLE DURING ITS FULL LARVAL AND ADULT STAGES

Specimen Number	Larval stage in days	Area eaten during larval stage	Adult stage in days calculated from active feeding period	Area eaten by adults during feeding period	Total area eaten by each insect during all stages
		sq. ins.		sq. ins.	sq. ins.
1	15	3·21	30	8·25	11·46
2	14	2·94	30	14·45	17·39
3	16	4·79	30	14·40	19·19
4	16	4·44	30	28·95	33·39
5	14	4·38	30	22·95	27·33
6	17	4·43	30	23·55	27·98
7	16	4·05	30	13·80	17·85
8	17	5·35	30	25·20	30·55
9	18	5·26	30	24·00	29·26
10	17	4·24	30	9·90	14·14
Total		43·09		185·45	228·54

It should be noted that while thirty days are taken as the average feeding period, some individuals are known to have fed for much longer periods. In one instance noted at Ottawa, an overwintering beetle fed freely from May 26 to September 19, a total of 117 days.

FOOD PLANTS

The Colorado potato beetle as has been shown is a major pest of the potato and a minor pest of tomato and eggplants. Other plants as, for instance, beans, are eaten at times, but the injury resulting therefrom is usually not extensive. In Canadian entomological literature, the following have been listed at one time or another: Cultivated oat, *Avena sativa;* smartweed, *Polygonum hydropiper* L.; lamb's quarters, *Chenopodium album* L.; maple-leaved goosefoot, *Chenopodium hybridum* L.; pigweed, *Amaranthus retroflexus* L.; hedge mustard, *Sisymbrium officinale* (L.) Scop.; red currant, *Ribes vulgare* Lam.; bittersweet, *Solanum dulcamara* L.; three-flowered nightshade, *Solanum triflorum* Nutt.; nightshade, *Solanum nigrum* L.; ground cherry, *Physalis* sp.; black henbane, *Hyoscyamus niger* L.; apple of Peru, *Nicandra Physalodes* (L.) Pers.; thorn apple, *Datura stramonium* L.; thoroughwort, *Eupatorium perfoliatum* L.; thistle, *Cirsium lanceolatum* (L.) Hill; tobacco, *Nicotiana affinis* and *N. sanderæ.*

Experiments with the following food plants for the larvæ, at Ottawa, all gave negative results, the larvæ dying when given only the leaves of tomato, bittersweet, ground-cherry or common nightshade.

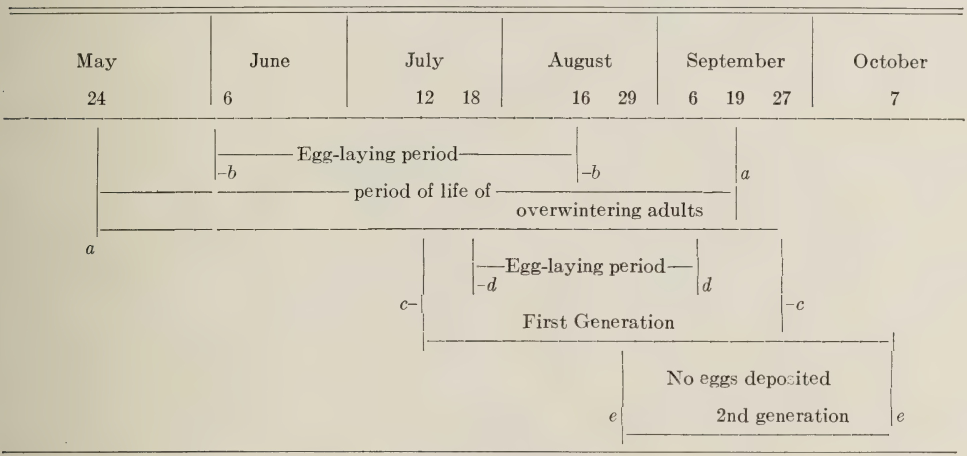
Mr. Norman Criddle has informed us that in Manitoba the beetle feeds extensively upon the three-flowered nightshade and that this plant is a factor of importance in enabling the insect to perpetuate far removed from potato plants. He has also found the beetles feeding and ovipositing on *Physalis lanceolata* Michx. and *Hyoscyamus niger* L.

THE NUMBER OF GENERATIONS PER YEAR.

The breeding records obtained at Ottawa in 1919 showed that there were that year two distinct generations of the insect, the first occupying thirty-six days from the laying of the eggs on June 6 to the emergence of the adults on July 12, and the second generation forty-two days from the laying of the eggs on July 18 to emergence of the adults on August 29. The beetles of the second generation did not mate or lay eggs that autumn. Some went into hibernation early in September while others remained active until October 9.

There was considerable overlapping of the generations, the overwintering beetles continuing to lay eggs over a long period from June 6 to August 16, and the females of the first summer generation from July 18 to September 6. This is shown in the following chart:—

CHART: THE APPROXIMATE GENERATIONS OF THE COLORADO POTATO BEETLE IN THE VICINITY OF OTTAWA, 1919



Key: *a–a* = Period many of overwintering beetles lived after emerging from hibernation quarters about May 24.
b–b = Period during which overwintering beetles deposited eggs.
c–c = Period during which first generation beetles emerged and remained active.
d–d = Period during which first generation beetles deposited eggs.
e–e = Period during which second generation beetles emerged and remained active.

The breeding experiments carried on in New Brunswick have shown that normally there is only one full generation in that province per year. This generation is the direct result of the eggs laid by overwintering beetles and requires about fifty-eight days for development. Egg-laying by the beetles which emerge from the soil in spring may continue through June, July and part of August, so the generation is extended over a large part of the season and larvæ may be found in the field in autumn. All efforts to secure mating between the beetles of this generation in the summer have failed, although mating has been secured between the males of the summer generation and females of the preceding overwintering generation. That there is only one generation in the year has also been the finding in tests carried on by Dr. W. H. Brittain, Provincial Entomologist for the Province of Nova Scotia.

The following are the dates of the different stages as found in New Brunswick in comparison with those noted at Ottawa:—

—	Ottawa, 1919	New Brunswick, 1921	New Brunswick, 1922
1. Beetles first emerged from soil	May 24	May 28	May 30
2. First eggs deposited	June 6	June 1	June 2
3. Eggs hatched	" 13	" 15	" 15
4. First moult	" 16	" 21	" 19
5. Second moult	" 18	" 24	" 22
6. Third moult	" 20	" 27	" 26
7. Pupation	" 24	July 6	July 6
8. Adults emerged	July 12	" 28	" 29
9. Eggs of second generation	" 18		
10. Eggs hatched	" 24		
11. First moult	" 28		
12. Second moult	" 31		
13. Third moult	Aug. 3		
14. Pupation	" 6		
15. Beetles emerged	" 29		
16. Last beetles seen active	Oct. 7	Oct. 9	Sept. 28

HIBERNATION

Overwintering beetles have been found to begin entering the soil for hibernation by August 12 in New Brunswick and August 30 in Ottawa. In the latter district, under insectary conditions they continued to enter the soil at intervals until September 20, on which date the last individuals went into hibernation. The adults of the first summer generation were found at Ottawa to enter hibernation at an earlier date. Of 140 individuals, reared from eggs of overwintering beetles which emerged from pupal cells between July 12 and July 23, 15 per cent had hibernated by July 21, 35 per cent by July 30, 75 per cent by August 23 and the remainder by September 29. Many beetles of this generation laid but a few eggs and some of them none at all. In the Ottawa district, beetles of the second summer generation which emerged from the pupal cells on August 29, went into hibernation by September 18. The male beetles were always noticed to hibernate before the females.

In wintering-cage tests with beetles in New Brunswick several lots were forced into hibernation at an early date by confining them in wire cages on the soil with only a limited supply of food, enough for one day. Some of the beetles were found to burrow down at once, while practically all went down within three days after the food was gone. Collections of 200 beetles were made and placed in these cages on August 30 (two lots) September 5, 10, 13, 27 (twelve lots), September 30 and October 1 and 5 (sixteen lots). From the first three lots put in the cages on August 30 and September 5, 205 beetles out of the 600 emerged the following spring. Out of the third lot of 200 put in on September 10, 42 emerged the following year, while out of a total of 3,320 beetles put in cages on September 13 and later, only 360 emerged in the spring. This would seem to indicate that the beetles hibernating early in autumn wintered a little better than those entering the soil late in the fall.

Depth at Which Beetles Hibernate.—The beetles commonly go into the soil immediately below the place where they have been feeding last. If a plant, they will be found beneath it; if a pile of tubers left in the field after harvesting, they will be below or to one side of it. Numbers of beetles often cluster around such piles of small or decaying tubers in the fall and beneath the remains of such a pile is a good place to find the beetles in spring. Following the plough in an old potato field in spring is another method of finding hibernating beetles.

In a loose, open soil over a clay subsoil at Ottawa, beetles were found to have penetrated to a depth of 14 inches, going right through the surface soil and into the clay subsoil. Beetles which hibernated in the insectary were found to go down to a similar depth. In New Brunswick, the beetles have been found at different depths in clay and in sand loam. In a damp, cold clay-loam, beetles have been found within 2 inches of the surface and none at all below 6 inches, while in a loose, sandy soil only a few hundred feet away none were found at less than 14 inches and some at 17 inches. In a dense gravel-loam soil only an occasional beetle was turned out when the plough was cutting 5 inches deep, but a number could be found by digging 3 inches more in the bottom of the furrow.

Loss of Weight in Hibernation.—At Ottawa, a number of beetles were weighed just prior to hibernation and again one month later. It was found that each beetle had lost an average of ·020 grams, which may have been due to evacuation of fæces.

Death Rate in the Winter.—The death rate in winter is hard to estimate from the little information available, but considering the very large numbers of adults seen in the fields in autumn and the much smaller number which appear in spring, it must be large even in ordinary years. The few wintering-cage tests indicate this to be the case and collecting the beetles behind the plough in old potato fields in spring supports it by showing that some 25 per cent of the beetles turned up and seen are dead.

Hibernation Through Two Winters.—The only published records of hibernation through two winters which we have found are those of Tower[24] and Girault[27]. Tower, by reducing the moisture content and keeping the temperature of a cage high, brought about continuous hibernation from September, 1902, to May, 1904, a period of twenty months. The beetles surviving this long rest reproduced in a normal manner. He does not mention whether they hibernated again or not.

Girault mentions that in his experiments a male beetle had apparently hibernated through the winter of 1906-1907 and again through the winter of 1907-1908.

In September, 1919, at Ottawa, 37 overwintering beetles remained of 100 collected the preceding May and used in breeding tests through the summer. By September 15 these had gone into hibernation for the second time. Early in October these beetles were buried 14 inches deep out of doors to see whether they would live through the winter. In May, 1920, they were dug up and 30 found in a healthy condition. These were placed in a tin box and shipped to Strathroy, Ont., where the assistant who had looked after the experiment the previous year was then stationed. In the insectary at Strathroy these beetles produced eggs freely but as the pairs had been mixed together in shipment in a single box, no special effort was made to keep a record of the eggs laid by individual beetles. The eggs laid were fertile and hatched normally.

NATURAL CONTROL FACTORS

Egg-eating by Beetles

In the Field.—An instance was noted at Ottawa, in 1919, of a Colorado potato beetle eating an egg mass of its own kind but as no others were seen at the time to do the same, it was thought to be of rare occurrence. This habit had been noted by Norton in Maine, 1911[31]. Field collections and insectary

[24] An investigation of Evolution in Chrysomelid Beetles of the genus Leptinotarsa: Carnegie Institution, Wash., D.C., 1906.

[27] Annals Ent. Soc. Amer., I, 176.

[31] Canadian Entomologist, XLIII, 385.

breeding tests in New Brunswick in the years 1921 and 1922 have shown that the egg-eating habit is common under certain conditions and in some seasons may be a fairly effective form of natural control.

The first egg-eating noticed in the field was on June 1, 1921, a cold day, when little leaf eating was going on (temperature 56° F.). A female potato beetle was seen eating an egg mass on a leaf. This was unusual, so the time was noted and the beetle watched until the egg mass was consumed. This was accomplished in a little over twelve minutes. The beetle then started to move away. It was captured and taken to the insectary where it was confined in a glass tube and given other leaves bearing egg masses for food. The eggs in the masses were counted before being given to the beetle and any eggs remaining when the food was changed were also counted. The following is a record of the eggs consumed by this beetle.

June	1. Egg mass in field (probably 30 eggs)	30 eggs
"	4. 2nd egg mass consumed	37 "
"	5. 3rd egg mass consumed (at 2:30 p.m.)	41 "
"	5. 4th egg mass, partly consumed (at 6:30 p.m.)	29 "
"	7. 5th egg mass consumed	24 "
"	7. Beetle laid 53 eggs, which were removed	
"	9. 6th egg mass consumed	23 "
"	11. 7th egg mass consumed	36 "
"	25. Beetle laid 3 eggs and later died	
	Total eggs eaten	220

The eggs laid on June 7 and removed from the cage were fertile and hatched on June 22.

Following the discovery of egg-eating in the field on June 1, a search was made to find to what extent it was going on. On June 2, 328 egg masses were collected in different fields and the eggs of each counted. Three hundred and three which showed no signs of injury had a total of 6,177 eggs. Twenty-five partly eaten masses had 264 eggs remaining. At the same average number as the others there should have been 762, so that of this lot it would appear that some 498 had been eaten, or 7.2 per cent of the whole number.

In all field collections afterwards a careful examination was made of the masses for signs of injury and it was found easy to locate the shells of egg masses which had been either partly or wholly eaten. Masses which had been completely destroyed were found to be more common than those partly eaten.

EGG MASSES FOUND PARTLY OR WHOLLY EATEN IN THE FIELD

Date	Number destroyed	Percentage of day's collection	Percentage partly destroyed	Percentage of day's collection
June 1	1	1·5	7	10·7
" 2	0	0	25	7·6
" 4	35	15·8	15	11·3
" 6	25	11·0	0	0
" 8	19	11·1	0	0
" 10	3	6·5	0	0
" 18	11	3·7	0	0
" 21	5	3·9	0	0
Total	99	....	47	....

99 egg masses destroyed = 2.8 per cent of total season's collection of 3,455 masses.
47 egg masses partly destroyed = 1.3 per cent of season's collections.

146 masses attacked = 4.1 per cent of season's collections.

After June 10 egg-eating was not seen again until June 18 and June 21. Warmer weather is thought to have been responsible for this since the habit has only been observed on cool days. The weather during the first ten days of June, 1921, was cool.

WEATHER RECORD, GREY'S MILLS, N.B., JUNE 1 TO 10, 1921

Date	Temperature			Humidity mean of three readings	Wind
	Max.	Min.	Mean		
June 1	56	54	55·0	69	N.W. gale
" 2	64	48	56·0	60	N.W. breeze
" 3	57	56	56·0	92	S.W. "
" 4	64	55	56·3	55	S.W. "
" 5	64	47	55·5	64	S.W. "
" 6	69	47	58·0	61	S.W. "
" 7	76	49	62·5	61	S.W. "
" 8	80	58	69·0	52	S.W. "
" 9	79	56	67·5	73	
" 10	82	59	70·5	75	

The first ten days of June, 1922, were fine and warm. No egg-eating was seen, either in the cages or in the field, until cold and damp weather began on the 11th. This lasted for four days, the maximum temperature in that time being 66° F. and on one day only, 50° F. During those four days, egg-eating was common in the cages and in the field. Of 100 egg masses collected on the 11th, 47 were partially eaten. A similar collection in another field on the following day showed 63 masses wholly or partially eaten, and one on the 14th showed 74. With the return of warm days, the destruction of eggs stopped at once, but in those four days a considerable part of the eggs in the field had been destroyed.

Another period of egg-eating occurred in the third week of July and was again associated with a period of cool weather. For three days the weather was cool, the temperature dropping on one day to a maximum of 58° F. Egg-eating was noticed in the breeding cages and field collections showed that it was common there. Of 100 masses collected, 27 were wholly or partially eaten. On the following day the proportion had increased to 34 out of 100. On the return of warm weather the following day, egg-eating in the breeding cages stopped at once and no signs of fresh injury were later found in the field. This occurrence of the habit in a cool period of July would seem to emphasize its relationship to temperature variations.

These notes on a curious habit of the insect are of particular interest as offering a possible explanation of a phenomenon frequently observed by potato growers. Some years, when the beetles emerge from the soil in usual numbers and promise to be as great a pest as in other years, the growers of potatoes are surprised to find that the larvæ are slow in appearing and that less damage than usual is caused. Sometimes in one locality the larvæ will be scarce while in other places they will be abundant, and occasionally they will be slow in appearing over a large territory. Such a phenomenon over a large territory is usually associated with a cold and backward spring and in a small area is often associated with some local condition tending to modify climatic conditions, such as fog, cold wind off the sea, or excessive rainfall. There are a few places in the Maritime Provinces where the potato beetle is reported never to appear in injurious numbers. While the reason for this is not known, it is noticeable that such places are always by the sea and in situations subject to fogs or cold winds.

Egg-eating in the Breeding Cages.—A number of pairs of beetles were confined in lantern-globe cages for records of eggs laid by individual beetles. Egg-eating was found to be common in these cages during the period of cool weather between June 1 and June 10, 1921. The eggs laid were removed from the cages twice daily and counted, so an accurate record was kept of the number laid. Where some were eaten, the bases of the egg shells remained to show the number. The list following shows the number of eggs laid and eaten. More might have been eaten if the eggs had not been removed at 12 and 5 o'clock daily. On several occasions a feast was interrupted by the removal of the eggs.

Date	Eggs laid that day	Eggs eaten by beetles	Percentage of eggs eaten
June 2	195	131	67·1
" 3	60	40	66·3
" 4	339	47	14·1
" 5	338	5	1·4
" 6	137	12	8·7
" 7	992	190	19·0
" 8	439	0	0·0
" 9	400	20	5·0
" 10	423	85	20·0
	3,323	530	12·9

Number of masses laid	145
Number of masses attacked	32
Number of beetles	50 (25 pairs)

Other Predators.—A number of insects have been recorded from time to time as attacking the larvæ of the potato beetle. Few of these have ever appeared in sufficient numbers to be of economic importance, with the exception of the two predaceous bugs, *Perillus circumcinctus* Stal., and *P. bioculatus* Fabr., which have been in some years of considerable importance in Ontario. The ground beetle, *Lebia grandis* Hentz, and the ladybird beetle, *Anatis quindecempunctata* Oliv., are also important enemies of the insect.

Parasites.—For an insect of wide distribution and great abundance the potato beetle appears to have very few parasites. In our work, extending over five years, only one parasite has been found, the tachinid fly, *Phorocera doryphoræ* Riley, and that only in very small numbers.

Fungi.—In 1919, at Ottawa, a number of the egg masses in the field were found to be coated with a fungus, identified by Mr. H. T. Gussow, Dominion Botanist, as belonging to the genus *Mucor*. He was not, however, prepared to state that the fungus was the primary cause of the non-hatch of the eggs.

Birds.—Several species of birds are known to feed upon the Colorado potato beetle. The Rose-breasted Grosbeak, which occurs commonly in Canada, devours the larvæ as well as the adults. It has, in fact, been referred to as the "potato-bug bird." The Bob-white, which occurs in southern Ontario, also feeds upon the beetle. The Ruffed Grouse, the Sharp-tailed Grouse, the Cardinal, the Yellow-billed Cuckoo, the Nighthawk, and the Prairie Chicken are other birds which have been recorded as feeding upon the beetle.

Wind Abrasion.—Field observations in 1921 and 1922 have shown that after a strong wind in June and July, a number of egg masses can be found in the field in a wet and mud-coated condition. Examination of such showed that a number of the eggs were broken and the contents mixed with dust made a paste over the others. On the soil could be seen the marks where the leaves

had been beaten backward and forward against it and there is little doubt that this beating had been responsible for the injury to the eggs, which by their position on the underside of the terminal leaflets are particularly exposed to such injury. It is most noticeable in fields where the rows are parallel to the direction of the wind. The remains of egg masses which have hatched may also be found but no traces of the larvæ, and it is possible that on leaves which strike the ground during a wind the helpless young larvæ may be destroyed by direct force or by being swept off and covered with dust.

Absence of Snow.—The absence of snow in winter seriously affects the numbers of beetles which hibernate successfully. It has frequently been observed, particularly by Mr. Norman Criddle in Manitoba, that large numbers of the beetles fail to live through winters during which the ground is not covered by snow. In this latter province in the winter of 1923-24, fully 90 per cent of the beetles were killed by frost, due to lack of protection from snow. Such a factor is undoubtedly of great importance as a periodic check to the insects.

ARTIFICIAL CONTROL*

The larvæ, or grubs, and adults of the Colorado potato beetle may be easily and effectively controlled by either dusting or spraying with various insecticides. Those commonly used are the arsenical insecticides, although various others are on the market which are more or less successful, if used according to the directions accompanying them.

General Insecticide Information.—The insectide to use, and the manner of applying it, depends upon several factors. In a dry climate where potato blight is not troublesome, the insecticides may be used alone, but in localities where potato blight is prevalent the insecticides should be combined with Bordeaux mixture. Again, where fungous diseases are of small consequence, the practice of dusting is, on the whole, more economical and speedier than the practice of spraying. Where fungous diseases are troublesome either spraying or dusting may be followed, preferably the spraying where there are good water facilities and where labour is available, but dusting may be followed where water facilities are poor or where large areas have to be covered with a minimum of labour.

The materials to use also depend upon several factors. In dry climates superfine white arsenic, the cheapest of all arsenicals, mixed with some purely inert filler, such as flour, may be satisfactorily used as a material for dusting, but in moist climates such a material would be liable to produce foliage injury.

Regarding the amounts of arsenicals to use, it may be taken as a rough guide that the particular arsenical being dealt with should be used in such a manner that approximately one pound, or just a little less, of metallic arsenic be applied to one acre of full-grown tops. For example, arsenate of lime contains 26 per cent metallic arsenic and, therefore, nearly four pounds of arsenate of lime should be used per acre of full-grown tops.

Spraying.—The control of the potato beetle depends upon thorough spraying, that is to say, the foliage should be well covered with the material applied. As a rule, at least 80 gallons of spray material, but preferably 100 or 120 gallons should be applied per acre, per application, upon tops of moderate size. Of materials to use, either 2 pounds of dry arsenate of lead, $1\frac{1}{2}$ pounds of arsenate of lime, or one-half to three-quarters of a pound of Paris green may be used to 40 gallons of water. With the latter it is advisable to add one or two pounds of quicklime in order to insure against slight burning of foliage.

* Prepared in consultation with Mr. Arthur Kelsall, in charge of insecticide investigations.

When spraying, applications of insecticides are generally made in conjunction with Bordeaux mixture, and in districts specializing in potato growing the insecticides so used are generally arsenate of soda, arsenate of lime, or arsenite of soda. Any one of the above three are used because they are the most economical. In localities where small areas of potatoes are grown for home use or for local trade the insecticides generally used are either Paris green or arsenate of lead, these being used purely because they happen to be older insecticides and consequently better known.

When insecticides are used with Bordeaux mixture the latter should be made somewhat in accordance with the following formula and the following directions. Of course, when this mixture is being used in quantity other more rapid procedures suggest themselves and information can be obtained concerning them from literature dealing more particularly with spray materials.

Copper sulphate (bluestone), 6 pounds.
Unslaked lime, 4 pounds.
Water (one barrel), 40 gallons.

Dissolve the copper sulphate (by suspending it in a wooden or earthen vessel containing four or five or more gallons of water). It will dissolve more quickly in warm water than in cold. Slake the lime in another vessel. If the lime, when slaked, is lumpy or granular, it should be strained through coarse sacking or a fine sieve. Pour the copper sulphate solution into a barrel, or it may be dissolved in this in the first place; half fill the barrel with water; dilute the slaked lime to half a barrel of water, and pour into the diluted copper sulphate solution; then stir thoroughly. It is then ready for use. (Never mix concentrated milk of lime and copper solution).

A stock solution of copper sulphate and milk of lime may be prepared and kept in separate covered barrels throughout the spraying season. The quantities of copper sulphate, lime, and water should be carefully noted. Bordeaux mixture deteriorates with age and should be used as soon as made.

Dusting.—Under most conditions arsenate of lime is the most economical material for dusting purposes against the Colorado potato beetle. Satisfactory dust may be obtained by utilizing 50 pounds to the acre of a dust composed of 8 per cent arsenate of lime and 92 per cent hydrated lime; or, a dust containing a much higher percentage of the arsenate of lime may be used, in which case a corresponding less amount of total dust per acre would be applied, all according to the type of dusting which is being used. Paris green is often used in dust form generally being mixed with either land plaster or hydrated lime, the Paris green constituting about 5 per cent of the mixture.

Using the insecticide in conjunction with Bordeaux mixture, a formula which is followed in some sections is, 12 pounds dehydrated copper sulphate, 8 pounds of arsenate of lime and 80 pounds of hydrated lime, which dust is used at the rate of about 50 pounds per acre. A more concentrated dust, say, one containing 25 per cent dehydrated copper sulphate, 15 per cent arsenate of lime, and 60 per cent hydrated lime may be used, applying about 25 pounds per acre. Generally better distribution and adhesion is obtained when the larger amount of dusts are used per acre, but frequently such dusts may be purchased cheaper in more concentrated form. Dusting should be done when the air is calm and preferably when the plants are moist with dew or from a recent rain.

When to Apply Sprays and Dusts.—The first application of material should be made generally when the plants are from 6 to 10 inches high. By this time large numbers of the eggs laid by the over-wintering beetles will be hatched. Additional applications should be made as required, generally at intervals of from ten to twenty days, during the period when the plants are green. As a rule, four or five applications are necessary.

PUBLICATIONS ON INSECTS

The following publications of the Department of Agriculture relating to insects are available on application to the Director of Publicity, Department of Agriculture, Ottawa:—

Pea Weevil, The....................C.P.L. No. 9
Lime, Arsenate of....................C.P.L. No. 10
Corn Borer, The Control of the European....................C.P.L. No. 16
Tent Caterpillars....................Circular No. 1
Flea Beetles and Their Control....................Circular No. 2
Chinch Bug in Ontario, The....................Circular No. 3
Insects and Their Control, Common Garden....................Circular No. 9
Tussock Moth, The Habits and Control of the White-marked....................Circular No. 11
Boring Caterpillars which are Liable to be Mistaken for the European Corn Borer....................Circular No. 14
The Control of Bark-beetle Outbreaks in British Columbia....................Circular No. 15
Army Worm, The....................Bulletin No. 9
Pear Thrips, The....................Bulletin No. 15
Apple Bud-Moths and Their Control in Nova Scotia....................Bulletin No. 16
Fruit Worms of the Apple in Nova Scotia, The....................Bulletin No. 17
Cleorini (Geometridae) Studies in North American....................Bulletin No. 18

NEW SERIES

Crop Rotation to Offset the Injury of Field Crop Insects....................Circular No. 2
The Date on Which it is Safe to Reseed Fields after they have been Devastated by the Pale Western Cutworm....................Circular No. 4
The Fruit Tree Leaf-roller and its Control in British Columbia....................Circular No. 10
How to Foretell Outbreaks of the Pale Western Cutworm in the Prairie Provinces....................Circular No. 12
The Beet Webworm....................Circular No. 14
The Control of Forest Tent Caterpillars in the Prairie Provinces....................Circular No. 19
The Walnut Caterpillar and its Control....................Circular No. 21
Two Insects Affecting Cane Fruits in British Columbia....................Circular No. 22
The Lesser Oak Carpenter Worm and its Control....................Circular No. 23
The European Earwig....................Circular No. 24
The Grasshoppers of British Columbia....................Circular No. 25
The Plum Curculio and its Control in Quebec....................Circular No. 27
The Apple Maggot and its Control in Quebec....................Circular No. 28
The Apple Curculio and its Control in Quebec....................Circular No. 36
Two Orchard Scale Insects, the San Jose Scale and the Oyster Shell Scale. Circular No. 37
The European Red Mite, a Pest of Fruit Trees....................Circular No. 39
The Strawberry Root Weevil, with Notes on Other Insects Affecting Strawberries....................Pamphlet No. 5
The Western Wheat-stem Sawfly and its Control....................Pamphlet No. 6
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